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Introduction

If sugar-beet plants are subjected to disturbances of parasitic or physiogenic nature the foliage will often assume a more or less pronounced yellow colour. Such chlorotic diseases, infectious as well as non-infectious, have appeared with varying prevalence in the Swedish beet-growing areas during the last decades. Some preliminary investigations into the non-parasitic yellowing of the beet foliage have been made in connection with studies (in course at present) on the biology of the Virus Yellows, an infectious beet disease which seems to be the principal cause of the yellow discolouration in the beets in the beet-fields in the province of Skåne during the nineteen-forties (Björling 1949, 1952). Among the former types of discolouration might be mentioned the diffuse chlorosis common during years in which a certain type of weather prevailed, for instance 1951; this phenomenon has been described by Elmers (1952), and is believed to have some connection with the changed proportions between the amounts of nitrates and phosphates in fertilizers which occurred during the last years of the nineteen-forties.

There occurs another type of non-parasitic yellow discolouration which is quite distinct from the above-mentioned chlorosis, and which seems to be recurring regularly. It has aroused a certain interest, partly because the symptoms exhibit so close a similarity to those of Virus Yellows that confusion between the two is possible, and partly because its incidence shows a marked increase since the middle of the nineteen-forties. Chemical analyses of foliage and soil indicate that, so far, the most distinctive feature of this yellow discolouration is an abnormally low magnesium content both of the plant and the surrounding soil. The disease may therefore provisionally be characterized as magnesium deficiency in analogy to manganese deficiency, boron deficiency, &c., although there does not appear to be a complete parallelism. In spite of the fact that several aspects of the aetiology and treatment of this probable deficiency disease are still obscure, it has been considered desirable to give a closer characterization of the symptoms by means of colour photographs and chemical analyses, in order to facilitate the diagnosis in field work, particularly at researches on plant pathology.

Symptoms

The first signs of disease appear rather late in the season, usually only during the latter half of July, in the form of narrow, pale yellow borders of the leaves, particularly at the tips of middle-aged or older leaves (Fig. 1). Even at this early stage of the disease the leaf-blades are thicker than normal, and more curly along the edges, the parts of the slightly thickened edges that are turned upward by the curling show up in the fields as distinct, very narrow yellow lines in the otherwise dark green foliage. In typical cases the symptoms then change rapidly; already after a week or so the chlorotic borders on the leaf edges have grown considerably, and appear as large, comparatively well-defined light yellow lobes oriented towards the centre vein and placed between or across the side veins (Figs. 2, 3). In most beet plants the chlorotic surfaces are light lemon yellow in colour, but individual plants may exhibit shades of dark yellow or orange.

At the same time as the yellow discolouration

on the leaves affected by magnesium deficiency begins to extend inwards in the direction of the centre vein, necrosis occurs at the leaf edges in the form of black or black-brown streaks and spots. In later stages of the disease the necrotic areas often grow centripetally, and may then more or less completely cover the chlorotic areas. The dark-coloured tissue at the leaf edges is so thin and brittle that it is easily broken by a touch or by wind action, the leaves consequently often have a frizzled and ragged appearence (Fig. 4).

The appearance of necrosis at an early stage in the disease as well as the shade and form of the yellow surfaces seem to be specific symptoms of magnesium deficiency. Even in beet plants with permanent slight symptoms, where the yellow discolouration during the whole course of the disease is confined to the narrow chlorotic borders at the leaf edges, there occur simultaneously with the initial symptoms or only a couple of days afterwards peripheral necrotic areas in form of small black spots or streaks. In the case of individual, particularly weakly reacting plants the yellow discolouration may be wholly absent, and only small black spots at the leaf edges indicate an insufficient magnesium supply.

By means of the above-mentioned details in the appearance of the diseased plant it is usually possible with reasonable facility to distinguish magnesium deficiency from Virus Yellows which exhibits similar symptoms. In the case of the latter disease the necrosis appears as irregularly spaced and lighter brown areas, the tissue is cartilaginous, and necrosis usually occurs only two to three weeks after the yellowing has set in. In the case of typical symptoms it is further quite easy to distinguish between magnesium deficiency and Virus Yellows by means of the shade of the yellow discolourations and of the form and distribution of the chlorotic surfaces. When it is a question of Virus Yellows the initial symptoms consist of more diffuse and more irregularly spaced yellow spots; in slightly later stages the whole leaf-blade except the veins often assumes a bright yellow colour (Fig. 5); in other cases there occur irregularly distributed yellow sectors limited by the largest veins (Fig. 6). The two diseases do not always, however, exhibit typical symptoms, as described above, and their diagnosis in the field may therefore be difficult, particularly in their later stages of development. In dubious cases it is advisable to make chemical analyses, and perform virus tests with aphids, or serological virus tests.

In typical cases of magnesium deficiency the leaf-blades are markedly thickened; on crushing them between the fingers they break with a crackling noise, exactly as in the case of Virus Yellows; this sound effect therefore cannot be exploited as a specific criterium of either of the beet diseases. When it is a question of magnesium deficiency the form of the leaves is often more triangular (Figs. 2, 4) or more kidney-shaped (Fig. 3) than is normally the case. When the deficiency is very pronounced the appearance of the plants is changed in various ways: they become more or less dwarfed with abnormally small and deformed leaves. sometimes with short and broad, sometimes with thin, very elongated petioles.

Different sugar-beet varieties — and probably also different plants of the same variety — react to magnesium deficiency with symptoms of varying strength. Regarding the variations within one and the same variety there is still no certain proof; the large differences in the strength of the symptoms in the case of adjacent plants in a field seem to indicate, however, that such variations do exist. In tests with different varieties when the tests happened to occur in fields where the plants had shown more or less pronounced symptoms of magnesium deficiency, it was possible to observe quite distinct differences in the strength of the symptoms in different beet varieties. In 1948 and 1951, for instance, a couple or foreign sugar-beet varieties showed stronger and more distinct symptoms of magnesium deficiency than the rest of the varieties tested.

Analyses of leaves with deficiency symptoms

Preliminary determinations of the magnesium content in leaves and petioles of varying age from sugar-beet plants with the above-mentioned symptoms showed that the magnesium content varies considerably in different parts of the foliage. The values obtained for the youngest leaves were on the average twice as high as those obtained for middle-aged or older leaves, while the petioles showed lower and more varying values throughout than the blades; in some cases only traces of magnesium could be found in the petioles, while determinable amounts were found in the blades. In order to eliminate as far as possible these variations pertaining to different parts of and stages of evolution in the plants, and to make the tests more reproducible, the analyses were only made on blades of fully developed, middle-aged leaves from plants free from symptoms of other beet diseases (Tables I to VI). Eight to ten leaves

Fig. 1 Fig. 2 Fig. 3

Fig. 4 Fig. 5 Fig. 6

Fig. 1—4 Magnesium deficiency
Fig. 5—6 Virus Yellows

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Table I.

ANALYSES OF LEAVES FROM FIELDS WITH SYMPTOMS OF MAGNESIUM DEFICIENCY

(Percent of dry substance)

Field No.	Districts	Leaves with symptoms: Sample No.	K	Na	Ca	P	Mg	Leaves without symptoms: Sample No.	K	Na	Ca	P	Mg
1	Kävlinge	50/1	3,95	2,74	0,73	0,25	0,13	50/2	4,07	4,83	1,90	0,21	0,27
1	»	50/3	3,03	4,62	1,06	0,24	0,14	50/4	2,32	5,82	1,54	0,27	0,62
1	»	50/5	3,73	3,30	1,23	0,29	0,15	50/10	5,97	4,18	1,30	0,37	0,26
1	»	50/8	3,22	3,68	0,61	0,30	0,17	—	—	—	—	—	—
1	»	50/9	4,39	4,33	1,27	0,36	0,12	—	—	—	—	—	—
1	»	50/6	4,02	5,01	1,45	0,27	0,21	—	—	—	—	—	—
1	»	50/7	2,71	6,78	2,12	0,18	0,17	—	—	—	—	—	—
2	Örtofta	50/39	4,23	2,50	0,80	0,27	0,29	50/38	3,39	2,10	0,90	0,28	0,43
3	Hököpinge	50/55	2,12	4,14	0,92	0,28	0,24	50/58	3,26	3,71	1,25	0,19	0,41
3	»	50/57	3,43	2,73	1,26	0,21	0,13	50/59	3,18	2,82	1,43	0,33	0,64
3	»	—	—	—	—	—	—	50/60	2,49	2,32	1,04	0,23	0,47
4	Hököpinge	50/43	4,22	2,98	1,05	0,32	0,28	50/44	2,53	2,81	1,68	0,23	0,63
4	»	50/45	4,79	2,91	0,85	0,29	0,11	50/46	3,94	1,88	1,04	0,32	0,43
5	Köpingebro	50/62	4,38	2,74	1,27	0,37	0,33	50/61	4,23	1,93	1,57	0,28	0,72
5	»	—	—	—	—	—	—	50/63	4.36	2,66	1,98	0,35	0,81
5	»	—	—	—	—	—	—	50/65	4,61	3,14	1,42	0,42	0,60
6	Köpingebro	50/67	3,98	0,96	0,41	0,29	0,12	50/72	4,40	2,12	1,01	0,22	0,42
6	»	50/69	3,69	1,72	0,85	0,24	0,20	—	—	—	—	—	—
6	»	50/70	4,41	2,32	0,94	0,25	0,29	—	—	—	—	—	—
6	»	50/71	2,66	2,08	0,55	0,32	0,14	—	—	—	—	—	—
7	Köpingebro	50/75	3,19	1,90	0,71	0,22	0,23	50/76	3,51	3,41	1,40	0,23	0,61
7	»	50/77	2,66	3,10	0,68	0,29	0,23	50/78	3,19	2,94	1,88	0,18	0,75
8	Karpalund	51/1	3,84	2,06	0,66	0,32	0,11	51/4	3,46	3,30	2,22	0,30	0,48
8	»	51/2	4,11	1,72	0,85	0,28	0,08	51/5	2,45	4,65	1,15	0,39	0,43
8	»	51/3	4,69	1,18	0,66	0,45	0,13	51/6	2,00	4,00	1,53	0,34	0,28
9	Hilleshög	51/18*)	2,10	2,60	0,52	0,25	0,11	51/21	2,88	2,84	1,19	0,28	0,40
9	»	51/19*)	2,46	2,36	0,40	0,26	0,15	—	—	—	—	—	—
9	»	51/20	2,42	2,90	0,63	0,27	0,13	—	—	—	—	—	—
9	»	51/22*)	2,40	2,24	0,51	0,30	0,10	—	—	—	—	—	—
9	»	51/23*)	2,45	2,58	0,74	0,26	0,14	—	—	—	—	—	—
10	Belgien	53/1	4,68	2,64	0,87	0,36	0,07	53/2	4,64	3,36	1,15	0,36	0,21
10	»	53/3*)	4,74	2,74	1,30	0,33	0,09	53/4*)	4,11	4,23	1,47	0,33	0,32
	Mean value	—	3,54	2,88	0,89	0,29	0,17	—	3,57	3,29	1,43	0,29	0,49

*) Klein Wanzleben

were taken from each plant; the leaves were dried, and the amounts of dry substance, potassium, sodium, phosphorus and magnesium then determined at the chemical analysis laboratory at the Royal Agricultural College, employing the standard methods of vegetation analysis in use at the laboratory.

The leaf samples were collected during the months of August and September in the years 1951 to 1953 from 21 different sugar-beet fields situated in the southern and middle parts of Sweden; further, a few samples were obtained from a field in Belgium. All samples were taken from plants belonging to the sugar-beet variety developed at Hilleshög, with the exception of a couple of numbers indicated in the tables. Taking into account symptoms and localities the material was divided into three groups, *viz.* leaves from plants with symptoms (10 fields, Table I); leaves from plants without symptoms growing in the same fields as the preceding group (10 fields, Table I); and finally, leaves from plants without symptoms taken from fields entirely free from symptoms (12 fields, Table II). Further, a number of analyses were made on leaves which exhibited yellow discolouration from other causes than magnesium deficiency, *viz.* Virus Yellows (Table III) and Downy Mildew, *Peronospora Schachtii,* (Table IV), in order to determine the magnesium in the leaves of plants attacked by these diseases; in both these cases the samples were collected in beet fields entirely free from symptoms of magnesium deficiency.

A comparison of the mean values for plants with and without deficiency symptoms from the

Table II.

ANALYSES OF HEALTHY LEAVES FROM FIELDS WITHOUT SYMPTOMS OF MAGNESIUM DEFICIENCY

(Percent of dry substance)

Field No.	Districts	Sample No.	K	Na	Ca	P	Mg
11	Örtofta	50/13	4,66	2,02	0,93	0,35	0,32
11	»	50/14	3,78	2,15	1,93	0,30	0,73
11	»	50/15	5,66	1,75	0,98	0,40	0,43
12	Örtofta	50/16	3,15	3,42	2,40	0,31	1,11
12	»	50/17	4,85	2,42	1,22	0,56	0,66
12	»	50/18	3,65	2,57	1,80	0,35	0,86
13	Örtofta	50/19	5,44	2,26	1,41	0,34	0,50
13	»	50/20	4,18	2,86	1,62	0,30	0,76
13	»	50/21	3,10	2,57	1,34	0,36	0,69
14	Karpalund	51/7	2,36	4,67	1,80	0,32	0,50
14	»	51/8	2,97	4,98	2,07	0,30	0,60
14	»	51/9	2,85	4,98	1,65	0,30	0,57
15	Karlshamn	50/79	4,60	2,62	1,87	0,27	0,52
15	»	50/80	4,50	1,79	1,92	0,30	0,57
15	»	50/81	3,98	2,91	1,54	0,30	0,47
16	Karlshamn	50/82	4,31	1,51	1,99	0,27	1,00
16	»	50/83	4,72	2,79	1,65	0,52	0,89
16	»	50/84	3,27	2,78	1,67	0,28	1,09
17	Karlshamn	50/85	3,88	3,18	1,17	0,32	0,38
17	»	50/86	3,91	3,65	1,38	0,33	0,57
17	»	50/87	3,98	2,24	1,57	0,34	0,54
18	Linköping	50/88	4,05	2,72	0,91	0,26	0,62
18	»	50/89	3,39	2,51	1,28	0,23	0,76
18	»	50/90	4,86	2,41	1,53	0,23	0,38
19	Linköping	50/91	4,30	4,37	1,94	0,23	0,92
19	»	50/92	2,78	4,11	1,70	0,29	0,97
19	»	50/93	2,81	3,71	1,69	0,28	0,81
20	Linköping	50/94	4,12	2,20	1,04	0,36	0,58
20	»	50/95	6,70	2,20	1,88	0,23	0,64
20	»	50/96	4,30	3,16	1,87	0,24	0,99
21	Ultuna	50/102	7,15	2,22	1,93	0,31	0,68
21	»	50/103	6,05	1,97	2,46	0,25	0,63
21	»	50/104	7,79	2,45	2,22	0,27	0,94
21	»	50/105	7,24	1,77	2,32	0,26	0,77
21	»	50/106	7,40	1,95	2,68	0,33	0,85
22	Arlöv	52/6	2,74	3,34	1,66	0,25	0,48
22	»	52/7	2,58	2,18	1,09	0,28	0,40
22	»	52/8	2,53	2,18	1,12	0,25	0,46
22	»	52/9	2,64	2,64	1,00	0,32	0,35
22	»	52/10	2,66	3,24	1,37	0,30	0,47
	Mean value	—	4,25	2,79	1,64	0,31	0,66

same field (Table I) shows that of the five determined substances potassium and phosphorus are practically unchanged, while sodium, calcium and magnesium shows lower values in plants with symptoms.

To take sodium first, the individual values within both plant groups vary considerably even in the same fields, and the decrease, amounting to about 12 percent, is not statistically reliable ($p = 0.2$). A comparison with the sodium content of plants from beet fields without deficiency symptoms (Table II) shows further that even lower mean values may occur in the case of perfectly healthy foliage, and it is consequently improbable that the absolute sodium content plays a primary part in the course of the disease under consideration. If the lower values found in leaves with deficiency symptoms do represent a real decrease in comparison with healthy leaves from the same field, it would rather be reasonable to suppose this phenomenon to be a secondary change in the proportions between some of the determined elements, a change caused by the course of the disease.

Table III.

ANALYSES OF LEAVES WITH SYMPTOMS OF VIRUS YELLOWS

(Percent of dry substance)

Field No.	Sample No.	K	Na	Ca	P	Mg
21	50/97	5,13	0,90	1,07	0,13	0,21
21	50/98	4,78	0,63	1,56	0,19	0,41
21	50/99	4,28	0,65	1,55	0,22	0,59
21	50/100	4,01	0,56	1,33	0,17	0,42
21	50/101	3,83	0,71	1,29	0,16	0,48
Mean value for leaves with symptoms		4,41	0,69	1,36	0,17	0,42
Mean value for leaves without symptoms						
21	50/102—50/106	7,13	2,07	2,32	0,28	0,77

Table IV.

ANALYSES OF LEAVES WITH SYMPTOMS OF DOWNY MILDEW

(Percent of dry substance)

Field No.	Sample No.	K	Na	Ca	P	Mg
22	52/1	2,73	3,80	1,50	0,15	0,61
22	52/2	2,52	2,28	1,04	0,21	0,51
22	52/3	1,83	2,12	1,00	0,18	0,41
22	52/4	1,57	2,42	1,20	0,17	0,49
22	52/5	2,05	2,85	1,30	0,18	0,69
Mean value for leaves with symptoms		2,14	2,69	1,21	0,18	0,54
Mean value for leaves without symptoms						
22	52/6—52/10	2,63	2,72	1,25	0,28	0,43

In leaves with deficiency symptoms the calcium content is markedly (about 38 percent) lower than in leaves free from symptoms, and this difference is statistically quite certain ($p < 0.001$). It cannot be assumed, however, that the comparatively low concentration of this element in chlorotic leaves plays a decisive part in the course of the disease. Quite apart from the fact that the symptoms of calcium deficiency are quite different both as to appearance and distribution from those of the disease discussed here, the fact that some of the corresponding soil samples were rich in calcium contradicts the assumption that there should be a primary deficiency of this element. Soil samples taken close to plants with deficiency symptoms showed in some cases extremely high calcium content, according to qualitative analyses of a magnitude of about 10000 p.p.m. In view of these facts it seems probable that the significantly low calcium content in leaves with deficiency symptoms is not a primary deficiency, but is connected with the abnormally low, but more easily explainable magnesium content in these leaves. This would seem to indicate that there might exist a determined proportion between magnesium and calcium, more so than between magnesium and the other elements under review, and that this fixed proportion to some extent would exist even in leaves with deficiency symptoms.

Regarding magnesium the decrease is significant in leaves with symptoms ($p < 0.001$); it amounts to 65 percent on the average compared to leaves free from symptoms in the same field (Table I), and to no less than about 74 percent compared to leaves from fields without symptoms (Table II). The magnesium content in leaves with and without symptoms also shows a good correlation with the amounts of available magnesium in the soil (Table V); and the proportions in which this element is present evidently play an important part in this connection. The sum-total of symptoms in the present case further show good agreement with the descriptions of magnesium deficiency given in modern literature abroad on the subject (Hull, 1949; Wallace, 1951; McKay, 1952). There are, however, very few chemical analyses published in connection with description of symptoms with reference to this deficiency disease; in the case of sugar-beets they are (to the author's knowledge) confined to vegetation analyses in a paper by Hale, Watson and Hull (1946). In this paper 14 samples (from different parts of England) of sugar-beet leaves with deficiency symptoms are analyzed, and the mean magnesium content is stated to be 0.15 percent of the dry substance (re-calculated here from 0.25 percent MgO), which is in good agreement with the results obtained in this investigation (0.17 percent, Table I). The English investigations did not, however, include soil analyses, and it is therefore impossible to make any comparisons on this important point.

A comparison between Tables I and II shows further that plants without symptoms from fields with deficiency symptoms have a lower mean content of magnesium, amounting to 26 percent, than healthy plants in fields free from

Table V.

ANALYSES OF SOIL SAMPLES

Fields with deficiency symptoms					Fields without deficiency symptoms				
		Mg p. p. m. in soil		Mg in leaves			Mg p. p. m. in soil		Mg in leaves
Field No.	Sample No.	Ammonium acetate	Morgan's solution	pC. of dry substance	Field No.	Sample No.	Ammonium acetate	Morgan's solution	pC. of dry substance
1	50/1	37	42	0,13	12	50/16	76	84	1,11
1	50/3	31	39	0,14	12	50/17	71	79	0,66
1	50/5	38	46	0,15	12	50/18	69	77	0,86
1	50/8	33	40	0,17	16	50/82	84	104	1,00
1	50/9	27	35	0,12	16	50/83	107	119	0,89
3	50/55	64	68	0,24	16	50/84	89	95	1,09
3	50/57	63	72	0,13	19	50/91	181	187	0,92
5	50/62	36	38	0,33	19	50/92	163	163	0,97
6	50/69	39	50	0,20	19	50/93	167	167	0,81
6	50/70	35	45	0,29	20	50/94	122	138	0,58
6	50/71	48	69	0,14	20	50/95	182	186	0,64
7	50/75	35	38	0,22	20	50/96	98	126	0,99
Mean value		41	49	0,19			117	127	0,88

symptoms. This difference is statistically certain (p practically equal to 0.001), and it points to the possibility that even plants without symptoms in fields exhibiting deficiency symptoms may not be sufficiently supplied with magnesium. It is difficult to give any absolute values in this connection, as it is certain that their magnitude is more or less influenced by other factors; to judge from the material collected here it seems likely that deficiency symptoms usually occur in beet plants when the magnesium content is less than 0.3 percent of the blade's dry substance, while the corresponding values in plants without symptoms from the same field may vary between 0.3 and 0.8 percent. The variations within the group designated »fields without symptoms» (Table II) are even larger, 0.3 to 1.1 percent, which, at least in part, may be explained by the fact that a couple of those fields (nos. 11 and 22) have mean values as low or lower than the mean value for plants without symptoms from fields with symptoms. If the last-mentioned plants can be characterized as not sufficiently supplied with magnesium, the same can probably be said about the plants from the fields without symptoms nos. 11 and 22. If this is the case, those fields can probably be placed in a not improbable category of fields with comparatively small deficiency of magnesium, a deficiency so small that no visible symptoms are caused in the plants. If fields nos. 11 and 22 in Table II are excluded, the magnesium content in plants from fields indubitably free from deficiency would vary between approximately 0.5 and 1.1 percent of the dry substance of the leaves.

Analyses of leaves with symptoms of Virus Yellows or Downy Mildew

The two above-named parasitic beet diseases cause chlorotic symptoms on middle-aged and older leaves; symptoms which, especially in their more advanced stages, may be difficult to distinguish from those caused by magnesium deficiency. A moderate number of analyses were performed according to the method described previously, in order to get an idea of the magnesium content in the leaves of plants attacked by these parasitic diseases. The leaves had medium severe, equally old symptoms of Virus Yellows and Downy Mildew respectively, and were collected from plants growing in fields where no visible symptoms of magnesium deficiency could be observed.

With regard to Virus Yellows Table III indicates pronounced and statistically certain decreases for all the elements included in the analysis, *viz.*: K 38 %, Na 67 %, Ca 41 %, P 39 % and Mg 46 % (for K, Na, Ca, P, $p < 0.001$; for Mg $0.01 > p > 0.001$). By and large, the proportion between magnesium and the other elements in healthy and in diseased leaves is constant, in contrast to the considerably changed proportions in leaves showing symptoms of magnesium deficiency. The absolute mean value for the magnesium content, 0.42 percent, in the leaves affected by Virus Yellows is probably in this case too high to be able to cause, by itself, visible deficiency symptoms (cf. Table I). However, the values for magnesium content show considerable variations in the different samples, and in one case (sample 50/97) the value is so low that in the absence of Virus Yellows typical magnesium deficiency symptoms probably would have been present. The decreases of the magnesium content caused by attacks of Virus Yellows seem therefore in some cases to lead to such low mean values that these by themselves would cause symptoms of deficiency; this phenomenon would be particularly common in fields with a small magnesium deficiency but without visible deficiency symptoms on the leaves (*i. e.* in fields where the magnesium content of the foliage amounts to 0.3—0.5 percent). Whether these conditions may occasion complex or deviating symptoms of primarily Virus Yellows has not been investigated.

Leaves affected by Downy Mildew show slightly higher magnesium content than healthy leaves (Table IV). The difference is fairly certain statistically ($0.02 > p > 0.01$), and any interplay between magnesium deficiency and Downy Mildew in the shaping of the typical symptoms of the latter disease seems therefore excluded. With regard to the other elements included in the analysis the affected leaves showed marked decreases of potassium ($p = 0.05$) and particularly of phosphorus ($p < 0.001$), while the content of sodium and calcium was practically unchanged. The very low values for the phosphorus content both in leaves affected by Virus Yellows and by Downy Mildew are very conspicuous in comparison with corresponding values for healthy leaves and for leaves affected by magnesium deficiency.

Soil analyses

Soil samples were in most cases collected at the respective localities at the same time as the foliage material. Preliminarily only a small part of these samples were analyzed with reference to the amount of soluble magnesium at the chemical analysis laboratory at the Royal

Agricultural College. The samples were selected in such a way that they represented on the one hand plants with typical symptoms of the disease from fields where the disease was common, and on the other hand healthy plants from fields wholly free from the disease. These preliminary investigations gave results which were unequivocal and sufficient in relation to the present work's character of description of symptoms in the field of plant pathology (Table V), and it was therefore considered unnecessary to make further investigations. In order fully to elucidate the causes of magnesium deficiency it would evidently be necessary to increase the number of soil samples and to analyze them not only with reference to the quantities of available magnesium, but also to the amounts of other mineral nutrients.

The air-dry samples were sieved twice (2 mm. and 1 mm. openings), and two analyses were made on each sample after extraction according to two different methods, first with Morgan's solution (0.5 mol. acetic acid, 0.74 mol. sodium acetate, pH 4.9), second with ammonium acetate (1 mol.); in both cases 10 gms. soil were treated with 50 ml. extraction fluid for 2 hours. The results of the analyses are shown in Table V. A couple of samples were not included in the table; they originated from two fields, one with symptoms and one without symptoms, which both were very rich in lime and presented methodological difficulties (qualitative analysis showed calcium contents between 5000 and 20000 p.p.m.). The values for the magnesium content in these samples diverged considerably depending on which of the two extraction methods that was used, and showed variations within the individual samples; they must therefore be considered uncertain and have consequently been excluded. Otherwise, the two series of soil values show a mutual uniformity with, throughout, slightly lower values in the case of extraction with ammonium acetate, and the values may therefore be accepted as a relative index of the amount of available magnesium in the individual samples.

A comparison between the magnesium values for fields with and without deficiency symptoms (Table V) shows conspicuous and statistically certain differences both for the soil and the corresponding foliage. In samples from fields without symptoms the amount of available magnesium in the soil is 2.5 to 3 times as large, on the average, and the absolute amounts of this element in the leaves 4 to 5 times as large, as in the samples from fields with symptoms. These agreements are so marked that they constitute a good argument for the assumption that the low content of magnesium in leaves with deficiency symptoms primarily derives from the small amount of available magnesium in the soil in the locality where the plants grow.

It is not possible, however, to obtain any explanation of the state of deficiency in the soil of the fields in question through the analyses either of the soil or of the foliage. In order to obtain a closer characterization of the fields with and without deficiency symptoms it would be necessary to make more detailed investigations of the soil, in the first place regarding the proportions between the various plant nutrients, but also of the soil structure and the conditions of water supply in the various fields. In this connection it would also be interesting to determine whether the frequently observed sparse incidence of plants with symptoms depends on variations in the soil with reference to available magnesium, or may be caused by genotypical differences of reactivity in different beet plants; for this purpose detailed investigations would also be necessary.

The Effect of magnesium deficiency on the yield

There are usually considerable difficulties accurately to gauge the decreases in yield caused by various plant diseases. This holds especially good for the physiogenic diseases, for instance the deficiency diseases, where the dividing line between »healthy» and »diseased» plants always is the reverse of sharp, and where all stages from insignificant to extremely severe attacks may be present in the same field. In order to obtain an approximate measurement of the effect of a deficiency disease on the crop, the best method is probably to perform fertilizing and spraying experiments with the element in question, and to study the effect of these proceedings on the symptoms and the yield. Neither in Britain (Hale, Watson and Hull, 1946) nor in Sweden, however, have such control measures given satisfactory results in the case of magnesium deficiency, with the compounds and methods employed so far. About 15 field trials were made in the province of Skåne during the years 1951/53, during which varying amounts of magnesium and other elements were supplied to the soil, but no unequivocally positive results could be observed with regard to the symptoms or the yield. The only conspicuous effect was a negative one: in a couple of experiments extra dressing with 500 kgms. 40 % potassium salt per hectare (2.47 acres) markedly accentuated the symptoms of magnesium deficiency. It

Table VI.

YIELD OF SUGAR-BEETS WITH AND WITHOUT SYMPTOMS OF MAGNESIUM DEFICIENCY

50 plants of each category

	Weight of foliage gms.	Weight of root gms.	Sugar content percent	Sugar gms.	Amount of noxious nitrogen	Conductivity
Without symptoms....	558 ± 28	434 ± 20	17,2	75	24	91
With symptoms	346 ± 18	275 ± 16	18,4	51	16	84

should be pointed out, however, that at several tests there occurred severe attacks of Downy Mildew and Virus Yellows, that the symptoms of magnesium deficiency consequently were more or less obscured, and that an accurate judgement therefore was impossible. In a couple of experiments no deficiency symptoms occurred at all, in spite of the fact that such symptoms had been observed in other fields on the same estate the year before. Such discrepancies often occur on one and the same estate, and it is therefore very difficult to make fertilizing tests of this type. In view of the above-mentioned disturbances only about ten of the tests fields were harvested; the results are tabulated in the Annual Reports on Experiments from the statistical bureau of the Swedish Sugar Corporation, years 1951/53.

Parallel with the fertilizing experiments other attempts were made to estimate the influence of magnesium deficiency on the yield in 1952. In August 50 plants with typical symptoms and 50 adjacent healthy plants were marked for individual harvesting and comparison in four fields. Because of severe attacks by Downy Mildew, and to some extent also by Virus Yellows, on the plants, three of these tests had to be discarded, and only one could be used (Table VI). The method of comparing the yield of healthy and of diseased plants is rather uncertain, for various reasons, and will give only a rough estimate of the magnitude of the decrease in yield at an attack of certain severity. In this instance the method meant only registering the difference between the two extremes: plants wholly without symptoms and plants with typically severe symptoms, growing in the same field; the difference between plants wholly without symptoms and plants with weak symptoms is certainly considerably smaller than the values shown in Table VI, to judge from ocular comparison on many occasions.

According to Table VI the weight of both foliage and root are conspicuously and significantly lower in plants with typical pronounced deficiency symptoms (34 and 37 percent respectively; p in both cases < 0.001). The sugar content is higher, however, in affected plants than in plants without symptoms, and the decrease in sugar yield in percent will therefore be slightly lower than the decrease of root weight. Further, the amount of noxious nitrogen and the conductivity are lower in affected plants. With regard to the changes both of sugar content and amount of noxious nitrogen the effects of magnesium deficiency seem markedly to diverge from those of a couple of other beet diseases with chlorotic leaf symptoms, *viz.* Virus Yellows and Downy Mildew, where the sugar content is regularly slightly lower, and the amount of noxious nitrogen considerably higher in affected plants. In spite of these indications of qualitative improvement, from the processing point of view, in plants with symptoms of magnesium deficiency, there are probably marked sugar losses as well as pronounced deterioration of the foliage in the case of severe attacks, and it should therefore be worth while to make a closer study of the disease with a view of elaborating effective control measures. Severe attacks that seriously affect the yield per acre are still comparatively rare (to judge from available surveys, *vide infra*), and the magnesium deficiency may therefore at present be considered less important than certain other diseases and pests that affect the sugar-beets (*e. g.* Virus Yellows and the sugar-beet eelworm.

The Frequency and geographical incidence of the disease

In connection with the annual survey of attacks of Virus Yellows and Downy Mildew, which has been taken since 1946, the occurrence of magnesium deficiency has also been noted in the field. Attacks have been observed in all the sugar-beet districts of the provinces Skåne, Blekinge, Öland and Östergötland. In general,

however, the frequency of the disease has been very low, amounting to only a few percent affected plants in the fields where the disease occurred; in districts outside the province of Skåne most of the examined fields were wholly free from symptoms, the same can be said of the inland districts of Skåne: the Örtofta and Staffanstorp districts. In the other districts of this province the disease was more wide-spread, though the intensity of the attack varied considerably; the magnesium deficiency seemed to be most prevalent in the Karpalund district on the plain south of the city of Kristianstad, further in the Hököpinge, and particularly in the Kävlinge district. More than half the number of the beet fields have been more or less markedly affected in the last-mentioned district during the last few years. In some cases practically all the plants in the fields have shown typical symptoms, with the exception of those growing on the headlands. The complete absence of symptoms in plants growing on the headlands is a characteristic trait of the magnesium deficiency disease in the fields; there is also the reasonably regular absence of affected plants in hollows and in places of more or less hard-trodden soil, for instance along the paths in experimental fields. These phenomena indicate that various factors may exert a modifying effect on the disease, and among those factors may probably be counted the structure of the soil, its capacity of retaining moisture, the amounts of fertilizer applied to the field, &c. The observations made so far do not indicate any certain relation between the types of soil and the distribution of the attacks. Severe attacks seem to occur more often on lighter soils, usually rich in lime; but distinct symptoms have been observed on all kinds of soils used for sugar-beet cultivation. Neither are the notations made in the field of the character and completeness to permit any conclusions on the question whether magnesium deficiency is more prevalent on farms without live stock than on dairy farms. It would seem reasonable to suppose that farms without live stock should be more liable to be affected, in view of the magnesium content of farmyard manure.

As mentioned in the introduction, the symptoms of magnesium deficiency have shown a marked increase in the beet-fields in Skåne since the middle nineteen-forties at which time the disease practically might be termed rare. In order to elucidate the causes of the increase it would be necessary to know the effects of the changes in farm economy, regarding fertilizing, which have occurred during the last decades. Several investigators studying plant nutrients, for instance Svanberg (1954), have pointed out the risks of the soil getting exhausted with regard to magnesium on continued intensive culture of cereal and root crops with the aid of nitrogen, phosphorus and potash in the form of fertilizers poor or wholly deficient in magnesium. It has been stressed, first, that the modern, concentrated potassium salts, as distinct from certain older types, *e. g.* kainite, do not contain any appreciable amounts of magnesium, and, second, that the appreciable amounts of this element present in farmyard manure (about 70 percent of the magnesium content of the forage crops) normally is returned to the soil on dairy farms, while on farms without live stock this is not the case. In addition to these factors (which should be given serious consideration) it should be pointed out with particular reference to sugar-beets that the quantities of fertilizers applied to the fields have shown a heavy increase during the last few years. This tendency is especially pronounced with regard to fertilizers containing phosphorus and potassium, while the nitrogen fertilizers show only a smaller increase. According to Elmers (1952) the relation N : P_2O_5 : K_2O to sugar-beets was in 1946 1 : 0.62 : 0.50, and in 1951 1 : 1.00 : 0.71. It is possible that both the absolute increase in the supply of these substances, and the changes in the proportions between them, have contributed to accelerate and reveal a state of magnesium deficiency (which in some places now is a concrete reality), through a process of developing or intensifying the visual symptoms. Several investigators have reported that increased dressings of potash may develop or strengthen the symptoms of magnesium deficiency in various plants (Cf. Bibliography Minor Elements, Vol. I/III), a phenomenon which was confirmed with regard to sugar-beets at some of the above-mentioned Swedish fertilizing experiments. It should further be mentioned that there is a possibility that the lower nitrogen supply (lower relative to other substances) may play a rôle in this connection; the symptoms of magnesium deficiency are accentuated when there is a lack of nitrogen according to several investigators (*inter alia* Wallace, 1951).

Summary

The symptoms are described of a non-parasitic yellow discolouration of the beet foliage, a phenomenon which has grown more common in later years. The most marked characteristic found so far is an abnormally low magnesium

content in both beet plants and surrounding soil. While magnesium contents of 0.1 to 0.3 percent of the dry substance were found in leaves with typical symptoms of the chlorosis in question, the corresponding values for leaves from plants without symptoms from the same field vary between 0.3 and 0.8 percent, and for leaves from healthy plants from fields without symptoms of magnesium deficiency between 0.3 and 1.1 percent. From soil adjacent to plants with symptoms mean values of 40 to 50 p.p.m. soluble magnesium were obtained by means of two different methods of extraction, while the corresponding mean values for soil from beet fields without symptoms were about 120 p.p.m.

Symptoms of magnesium deficiency were found to be a comparatively common occurrence in certain beet-growing districts of the province Skåne, while in the other districts the disease at present is rare. In its present prevalence the disease is considered a less serious danger to the sugar-beet crop than the attacks of certain other beet diseases and pests (*e. g.* Virus Yellows and beet eelworms). Attempts at control in the form of fertilizing and spraying tests have so far, with the compounds and methods employed, not given satisfactory results. In order to develop effective control measures it will probably be necessary to elucidate the causes of the magnesium deficiency, in particular through extended investigations of the soil.

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